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EFFECTS OF ROAD MANAGEMENT ON MOVEMENT AND SURVIVAL OF ROOSEVELT ELK

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Abstract: Road closures frequently are used to manage for Rocky Mountain elk (*Cervus elaphus nelsoni*), but no studies have evaluated the effects of limited vehicle access on movements and survival of Roosevelt elk (*C. elaphus roosevelti*). We studied movements and survival of female Roosevelt elk before Road Management Areas (RMA) were designated, and during limited vehicular access from 1991 to 1995. The Bureau of Land Management (BLM) instituted a limited-vehicle access program on 35% of the study area in 1992. We found a reduction in core area size ($P = 0.002$) and home range size ($P = 0.077$) during limited vehicle access. There was also a reduction in daily movement of elk ($P = 0.0001$), and there was a negative correlation between daily movements and percent association of elk home ranges with RMA. There was an increase in survival rate ($P = 0.03$) during the limited-vehicular access period compared to the pre-RMA period, and survival rate declined following the removal of the gates ($P = 0.05$). Our data suggest that limited-vehicular access reduces human disturbance that results in reduced movements and poaching (increased survival) of Roosevelt elk. Such methods should be considered for other elk populations.

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Key words: *Cervus elaphus roosevelti*, disturbance, home range, limited vehicle access, movement, Oregon Coast Range, roads, road closures, Roosevelt elk, survival.

Rocky Mountain elk have the ability to learn and adjust to favorable or unfavorable conditions, and preferred habitats may be deserted if disturbance is excessive (Craighead et al. 1973, Geist 1978). If elk attempt to minimize energy expenditures and maximize foraging efficiency as suggested by Geist (1982), then elk should avoid areas associated with human harassment and favor areas that maximize security. Thus, road closures should reduce human disturbance, and increase elk security. Elk normally do not range widely within their home range in the course of daily activities. Rocky Mountain elk typically move less than 1.7 km in 24 hours (Schoen 1977, Irwin 1978). Commonly, Rocky Mountain elk concentrate their activity at preferred foraging areas until making a larger move to another location (Lieb 1981). Under pressure from human disturbance, however, Rocky Mountain elk will flee preferred areas, and the amount of movement may increase (Edge 1982). Similarly, roads and disturbance by humans can influence elk survival. High poaching mortality of Roosevelt elk has been reported in an area with high road density in the Oregon Cascades (Stussy et al. 1994). However, other than harvest reports from hunters, there is little information on cause-specific mortality and survival rates for Roosevelt elk in the Oregon Coast Range, but estimates of survival rate are important for population modeling. Pope (1994) reported a survival estimate for Roosevelt elk of 0.896 (SE = 0.012) for 1 March 1991 to 28 February 1992. Potential causes of mortality in the study area for adult cow elk include legal harvest, poaching, cougar (*Felis concolor*) predation, disease, and malnutrition (Schwartz and Mitchell 1945, Toweill and Meslow 1977, Kistner 1982, Pope 1994).

We assessed the influence of limited vehicle access on elk movements and survival. We hypothesized that elk activity would shift toward RMAs, and this would be demonstrated by a higher percentage of home range and core areas within RMAs after roads were closed to the general public. We also hypothesized that the RMAs would provide security to elk, resulting in a reduction in elk movements. The reduction in elk movements would be demonstrated by a decrease in core area and home range size, and the distance moved between consecutive telemetry locations would decrease during the period of road management. Further, we hypothesized that the decrease in movement would be correlated with the degree of elk association with RMAs. Our final objective was to estimate survival rates and causes of mortality and their relation to the RMAs. We hypothesized that survival rates would be higher for elk associated with RMAs than for elk in the pre-RMA study, and that survival rates would be higher in the RMA period than after the gates were removed.

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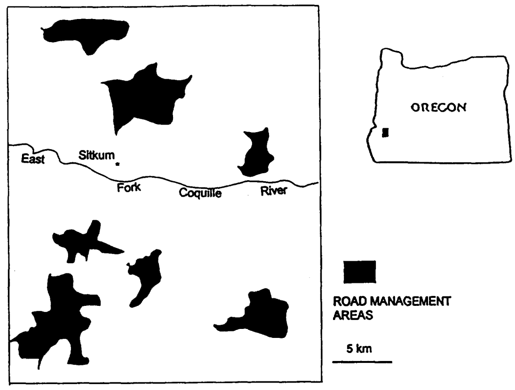

Fig. 1. Study area and Road Management Areas for Roosevelt elk in the southern Oregon Coast Range, 1991–95.

STUDY AREA

The study area spanned about 380 km^2 of the Coos Bay District of the BLM, including the northern Myrtlewood and southern Tioga Resource Areas. The area is about 30 km southeast of Coos Bay and 40 km west of Roseburg (Fig. 1). Typical of the Southern Oregon Coast Range, the terrain was dominated by steep ridges and mountain slopes, divided by extensive stream systems. Elevation ranged from 150 m along streams to 1,000 m on ridge tops. The climate is maritime, with moist winters and dry summers. Precipitation ranged from 97–218 cm per year from 1969 to 1992 (Oregon Climatological Cent., unpubl. data). Temperature during this time period ranged from a mean minimum of 1.67 C in January to a mean maximum of 25.93 C in August (Oregon Climatological Cent., unpubl. data). Deep and persistent snowfall is possible at high elevations, potentially blocking road access for up to 2 months. However, there were no snowstorms that prevented vehicle access to anywhere in the study area for >1 week during this study.

Vegetation consisted of the western hemlock (*Tsuga heterophylla*) series and until 2 decades ago was predominately late-successional Douglas-fir (*Pseudotsuga menziesii*) and western hemlock forests. Today, the landscape is a mosaic of recent clearcuts, Douglas-fir plantations and old-growth with some naturally regenerated mixed stands of western redcedar (*Thuja plicata*), red alder (*Alnus rubra*), bigleaf maple (*Acer macrophylum*), Douglas-fir and western hemlock. Riparian areas typically contain red alder, bigleaf maple and myrtle (*Umbellularia californica*). Understory vegetation is sparse in young Douglas-fir plantations, but can be quite dense in naturally regenerated stands and older seral stages. Sword fern (*Polystichum munitum*), huckleberry spp. (*Vaccinium ovatum* and *V. parvifolium*), vine maple (*Acer circinatum*), salal (*Gaultheria shallon*), rhododendron (*Rhododendron macropyllus*), and oceanspray (*Holodiscus dicolor*) are typical understory species. Land ownership in most of the area is alternating sections of BLM and private land. The area has been under intensive forest management with the most recent logging on private ownerships. Although commercial timber operations dominate the landscape, the area is also used for recreation including camping, hunting, trapping, and berry picking.

Access for forestry activities has produced an extensive road network within the study area. The BLM maintains paved mainline roads that also are used by the private companies to access and manage their forests. Rocked secondary roads branch from mainlines with rocked and non-rocked spur roads branching from secondary roads. Most roads are open to public access except during periods of high fire danger. One secondary road on private land was gated for a month during summer 1994, but no other roads were closed due to fire danger during this study.

METHODS

A 1-year study was conducted to determine movements, survival, and habitat selection of elk before limited road access (pretreatment phase). The second author (Pope 1994) conducted the pretreatment phase of the study from June 1991 to August 1992. Pope collected location data on 29 radiocollared cow elk; 20 of these original elk lived through the entirety of the study (~ 3.5 yr). These elk and 12 additional elk were monitored by the senior author (Cole 1996) during the RMA phase of the study from July 1993 to August 1994. After the removal of the gates, Cole monitored the elk for mortality between August 1994 and March 1995 (post-RMA phase).

Gate Placement and Road Management Areas

Motorized vehicle access was limited on 128 km of secondary and spur roads within the study area by installation and maintenance of 21 gates. Gate placement was designed to include the home ranges of as many of the original radiocollared elk as possible and access was limited to 7 discrete networks of secondary and spur roads (RMAs; Fig. 1). The closures were initiated in October 1992 at the end of the pretreatment phase (Pope 1994), which allowed a 9-month acclimation period, and remained in place until 20 August 1994. Road Management Areas made up about 35% of the study area.

The gates did not provide complete road closures. By definition, road closures prevent all vehicle access, and in some cases the road surface is destroyed, seeded and no longer maintained. Instead, the gates for this project limited vehicle access. The intent was to limit access to an average of ≤4 trips per week behind gates for administrative purposes such as forest management activities, wildlife research, fire suppression, and emergency access. True road closures would provide a clearly defined experimental treatment. However, the interspersion of private and public lands made closures logistically impossible to implement, and road management had to be a cooperative venture. Therefore, limited access was used for the study instead of complete road closures. Non-motorized access was not limited.

We compared vehicular traffic volume between gated and non-gated roads using magnetic loop traffic counters (Safetran model LDC355, Colorado Springs, Colo.). Despite administrative and illegal vehicle entries behind the gates, vehicular traffic on gated roads was consistently ≤4 trips per week throughout the RMA phase of the study (Cole 1996). In contrast, vehicular traffic on non-gated roads typically was 1.5–4 times that of gated roads during both the pretreatment and RMA phases (Pope 1994, Cole 1996). Thus, the RMA road treatment was considered successful for the purposes of this study.

Elk Captures

Twenty-nine cow elk were immobilized in March 1991 by personnel of Oregon Department of Fish and Wildlife with helicopter darting with carfentanil citrate as an immobilizing compound (Pope 1994). Pope attempted to capture elk from distinct bands throughout the study area and recorded location, estimates of age, weight, and physical condition for each captured elk. Radiotransmitters (Telonics MOD-600 164 MHz, Mesa, Ariz.) with a >3 year operational life were attached to each captured elk. Each collar contained an activity sensor that increased the pulse rate from 50 pulses per minute (ppm) in the head-down position to 100 ppm in the head-up position. To facilitate visual identification of collared elk, numbered and color-coded eartags were attached to each ear (Nasco TUFF-FLEX cattle tags, Modesto, Calif.). Twenty of these original 29 elk lived >3.5 years through all phases of the study. Twelve additional elk were captured in April 1993 with a helicopter and Hughs 500-C net gun without immobilizing agents. An effort was made to capture an equal number of elk within and outside RMAs and from distinct bands.

Radiotelemetry and Elk Locations

Telemetry procedures were described by Pope (1994). Two-element Yagi antennas with Telonics TR-2 receivers were used to locate elk. The "loudest signal method" as described by Springer (1979) was used to determine the direction of the radiosignal, and 3–5 compass bearings were used to locate elk by triangulation. All locations were plotted with Universal Transverse Mercator grid (UTM) coordinates on U. S. Geological Survey 1:24,000 quadrangle maps. To increase the accuracy of locations, we attempted to minimize the time elapsed between bearings and the distance between elk and the observer without influencing elk behavior. Elk locations were derived from azimuth and receiver information entered in the telemetry processing program XYLOG (Dodge and Steiner 1986), which provides a confidence ellipse (Lenth 1981, White and Garrott 1986) for each location. The confidence ellipse feature requires a measure of azimuth error. Potential triangulation error has been reviewed extensively in the literature (Springer 1979, Lee et al. 1985, Garrott et al. 1986, White and Garrott 1990: 47–75). Based on this review, we conducted a field trial to determine azimuth error and reduce telemetry error. Azimuths were estimated with TR-2 receivers and the loudest signal method on 50 unknown-transmitter locations at a variety of times, elevations, and distances from the transmitter. Average azimuth error was 5 degrees; we used this value to generate estimates of confidence ellipses around elk locations with the XYLOG program.

To assure independence of locations, the minimum interval between successive locations should be sufficient for the animal to move from one end of its home range to the other (White and Garrott 1990:147). Therefore, we subjectively set the minimum time between successive locations at 24 hours, and individual elk were located ≥1 time per week between July 1993 and August 1994. All locations were diurnal, and we alternated locations between midday and crepuscular periods for each elk. Randomization of elk locations was logistically impossible because of the size of the study area and the need to obtain ≥50 locations per elk to estimate home range size for each phase of the study. We did not attempt to confirm radiolocations visually to avoid disturbance of radiocollared elk. When radiocollared elk were located visually, we recorded UTM location, habitat type, band composition, date, time, and elk activity.

Home Range and Core Areas

We used the minimum convex polygon (MCP) method (Hayne 1949) to estimate home range size and the adaptive kernel (ADK) estimator (Worton 1989) to estimate home range size and distribution. The ADK is a nonparametric method that uses a smoothing parameter to reduce bias in the estimator. Home range estimates were calculated for the 31 elk with more than 50 locations. We computed utilization distributions of 95, 75 and 50% for the ADK and MCP methods using program CALHOME (Baldwin and Kie, unpubl. data).

Various researchers have used arbitrary home range use distribution levels such as 50% to define core activity areas of animals (Kaufman 1962, Michener 1979, Dixon and Chapman 1980). The biological significance of these arbitrary use distributions to define core area is questionable. Therefore, we used the harmonic mean method instead of a 50% ADK use distribution to estimate the size of core activity areas. This method uses a Chi-square test to determine at what point the existing distribution of locations exceeds a "uniform utilization distribution" (Samuel et al. 1985).

Study Design for Movement Hypotheses

To test for the effects of RMAs on elk movement, we used paired comparisons of the 20 elk common to the pretreatment and RMA phases of the study. To control for differences between the time periods not related to the gates, the elk were divided into 2 groups: (1) RMA elk with >30% of their 95% ADK home range within an RMA (n = 14). (2) Control elk with <30% of their 95% ADK home range within an RMA (n = 6). We performed paired t-tests (α = 0.05) on each group to test for differences between the pretreatment and RMA phases of the study. We tested for differences in: (1) home range and core area size, (2) percentage of core area and home range associated with RMAs, and (3) the distance moved between consecutive locations for each group.

Road Management Area Boundary Determination

Topography and cover (Basile and Lonner 1979, Lyon 1979) may ameliorate the effects of vehicular disturbance on elk. Whether or not vehicles are visible or audible may influence the degree to which road traffic disturbs elk. Ideally, the RMA boundary would have been defined taking visibility of roads into account. However, the mixture of slope, aspect, and vegetative cover conditions in the study area made this logistically impossible. Instead, the RMA boundary was defined as the midpoint between gated and the nearest non-gated road. Secondary road systems mapped by Coos and Douglas counties were imported into program ARC/INFO (Environ. Syst. Res. Inst. Inc. 1991). Additional spur and new secondary roads were digitized from 7.5 minute U. S. Geological Survey quads using the ARC/EDIT program within ARC/INFO (Environ. Syst. Res. Inst. Inc. 1991). Roads that were permanently out of use due to vegetation or other natural obstacles were removed from the GIS with ARC/EDIT. With the complete and edited road layer, the boundaries of the RMAs were digitized. Using the distance function, we generated a series of points that was exactly half way between gated and the nearest non-gated roads. These points were connected with a digitizer to produce a map of RMA boundaries.

For each of the 20 elk present during both the pretreatment and RMA phases of the study, boundaries of the 95% ADK home range and harmonic mean core areas were converted to ARC/INFO format. To test for changes in location of home range and core area after limited access, the intersection of each home range and core area boundary with RMAs was determined with program ARC/INFO. The percentage of home range and core area overlap with RMAs during the RMA phase was compared to the percentage of overlap during the pretreatment phase of the study using paired t-tests.

Movements Between Consecutive Locations

The distance moved between consecutive locations of individual elk was calculated in program Home Range (Ackerman et al. 1990) for the RMA and pretreatment phases. Because elk were not located at fixed time intervals between successive locations, the distance moved between locations was expressed per 24-hour period by dividing the distance moved by the number of days between locations, and these values were averaged for each elk for the entire year (ADMSL). These values are not absolute measures of the distance moved per 24-hour period, but they are indices of movement for comparison between the 2 phases. Paired t-tests were used to compare ADMSL for each elk during the RMA and pretreatment phases for control and RMA associated groups. Two Pearson correlation tests were conducted; (1) on the difference in ADMSL between phases (dependent variable) with percent RMA association (independent variable), and (2) on ADMSL for each elk during the RMA phase (dependent variable) with percent RMA association (independent variable).

Survival Rates

Elk were located ≥1 time per week during the pretreatment and RMA phases. Between the pretreatment and RMA phases (Sep 1992–Jun 1993) elk were monitored at 2-month intervals to estimate survival rates. After the removal of the gates (post-RMA phase), elk were monitored at 1-month intervals. If mortality was suspected due to similar successive locations or for constant transmitter pulse rate, we visually located the elk and determined time and cause of

Table 1. Change in core area (ha), 95% home range size (ha), and average distance moved between consecutive locations (ADMSL; m) for control (n = 6) and Road Management Associated elk (n = 14) between the pretreatment (1991–92) and RMA (1993–94) study phases for Roosevelt elk in the Oregon Coast Range.

	Control elk			RMA associated elk		
	Mean change	Paired-t value	P value	Mean change	Paired-t value	P value
Core area	−18.3	−0.25	0.81	−93.7	−3.88	0.002
Home range	0.00	0	1.00	−110.6	−1.92	0.08
ADMSL	13.2	1.09	0.32	−42.6	−6.07	0.0001

death. Cause-specific mortality was not considered in calculation of survival rates because scavenging animals often disturbed the carcasses and prevented determination of cause of death.

The staggered-entry adaptation of the Kaplan-Meier product-limit estimator was used to estimate survival rates (Kaplan and Meier 1958, Pollock et al 1989). A SAS program by White and Garrott (1990: 236–239) was used to calculate survival rates, and a Chi-square log rank test within the program was used to test for differences between survival curves at alpha = 0.05 (Cox and Oakes 1984). For comparison of survival curves relative to the RMA phase, the intervals were divided into equivalent intervals to compute the log rank test (Cox and Oakes 1984). The pretreatment interval was from 6 March 1991 to 31 August 1992, and the RMA interval was from 6 March 1993 to 31 August 1994. All elk (n = 29) were included in the pretreatment interval, but only elk associated with the RMAs (n = 21) were included in the RMA interval. For comparison of the RMA period with the post-RMA interval, all elk were included in the post-RMA interval (n = 31). For comparison with the post-RMA interval, only the 1 September 1993 to 31 March 1994 portion of the RMA interval was considered.

We conducted survival analyses 2 ways: (1) censoring elk that disappeared, and (2) treating elk that disappeared as poaching mortalities. Seven elk disappeared (loss of radiosignal and loss of visual location) between March 1991 and March 1995. Three of these elk disappeared after expected transmitter life and were censored from both types of analyses. The 4 elk that disappeared within expected transmitter life were probably killed by poachers. We observed suspicious activity (people driving the roads after dark) when the elk disappeared (Pope 1994). Although the bands that the elk disappeared from were frequently seen, there were no collared elk with them. Failure to locate elk visually makes transmitter failure unlikely, and poaching is the most likely type of mortality to produce these conditions.

RESULTS

Forty-one adult female elk were studied between 1991 and 1995. Twenty of the original 29 elk, and 12 elk captured in March 1993 were alive at the beginning of RMA phase. Of primary interest were those elk that were alive during both phases of the study and with >30% association with RMAs during the RMA phase (n = 14). Each elk was located 56–69 times during the pretreatment phase and 59–62 times during the RMA phase, 17% of which were visual and 83% by triangulation. Mean confidence ellipse size for elk locations (Dodge and Steiner 1986) was 1.16 ha.

Core Area and Home Range

There was a reduction in core area and home range size between the pretreatment and RMA phases of the study for RMA associated elk, but there was no change for control elk (Table 1). Mean core area size for control elk was 449 ha (SD = 195) during the RMA phase and 468 ha (SD = 176) during the pretreatment phase (change = −18.3 ha, paired-t = −0.25, P = 0.81). In contrast, core area size for RMA associated elk decreased from 399 ha (SD = 190) during the pretreatment phase to 304 ha (SD = 216) during the RMA phase, and this change was significant (change = −93.7 ha, paired-t = −3.88, P = 0.002). Mean 95% ADK home range size for control elk was 832 ha during both the pretreatment (SD = 260) and RMA phases (SD = 344). Elk associated with RMAs decreased mean home range size from 761 ha (SD = 485) during the pretreatment phase to 650 ha (SD = 415) during the RMA phase, and this decrease was significant at the 0.1 level of

Table 2. Average distance (m) moved between consecutive locations of RMA associated radiocollared elk (n = 14) for the pretreatment and RMA phases with the change between the time periods and percent association with Road Management Areas in the Oregon Coast Range.

Elk frequency	Distance 1991–92[a]	Distance 1993–94[a]	Change	% change	% RMA[b]
4.061	190	168	−22	−11.6	37
4.081	216	156	−60	−27.7	63
4.120	283	196	−87	−30.7	95
4.161	346	244	−98	−28.3	32
4.232	189	162	−27	−14.2	88
4.251	170	136	−34	−20.0	71
4.271	202	168	−34	−16.8	80
4.291	343	286	−57	−16.7	93
4.330	362	314	−48	−13.3	72
4.390	186	174	−12	−6.4	95
4.421	171	160	−11	−6.4	91
4.532	179	143	−36	−20.1	98
4.551	237	205	−32	−13.5	60
4.651	231	191	−40	−17.3	34
$\bar{x}$	236	194	−42.7	−17.4	72.1
SD	69.0	53.2	25.6	7.52	23.8

[a] Average annual distance between consecutive locations during pretreatment (1991–92), and RMA phases (1993–94).
[b] Percentage of association with RMAs for individual elk defined as percent overlap of home range with Road Management Areas.

Table 3. Average distance moved between consecutive locations (m) of control radiocollared elk (n = 6) for the pretreatment and RMA phases with the change between the time periods and percent association with Road Management Areas in the Oregon Coast Range.

Elk frequency	Distance 1991–92[a]	Distance 1993–94[a]	Change	% change	% RMA[b]
4.022	219	201	−18	−8.21	3
4.100	251	238	−13	−5.18	4
4.181	206	220	+14	+6.80	5
4.311	264	286	+22	+8.33	0
4.370	230	294	+64	+27.8	29
4.631	219	229	+10	+4.57	29
$\bar{x}$	232	245	+13.2	+5.69	11.7
SD	21.9	37.3	29.4	12.7	13.6

[a] Average annual distance between consecutive locations during pretreatment (1991–92), and RMA phases (1993–94).
[b] Percentage of association with RMAs for individual elk defined as percent overlap of home range with Road Management Areas.

significance (change = −110.6 ha, paired-t = −1.92, P = 0.08).

There was little change in the percent of core areas and home ranges intersecting RMAs between the pretreatment and RMA phases of the study. Mean core area overlap for control elk was 11.0% (SD = 15.2) during the pretreatment phase and 12.3% (SD = 17.6) during the RMA phase (change = 1.33%, paired-t = 0.63, P = 0.56). Similarly, mean core area overlap with RMAs for RMA associated elk was 78.1% (SD = 24.7) during the pretreatment phase and 80.4% (SD = 19.5) during the RMA phase (change = 2.3%, paired-t = 0.48, P = 0.63). Mean 95% ADK home range overlap with RMAs for control elk was 12.3% (SD = 12.2) during the pretreatment phase and 11.7% (SD = 13.5) during the RMA phase (change = −0.67%, paired-t = −0.24, P = 0.82). Likewise, there was no change in home range overlap with RMAs for RMA associated elk; mean overlap during the pretreament phase was 70.1% (SD = 22.0) and 72.1 (SD = 23.8) during the RMA phase (change = −0.67, paired-t = 0.79, P = 0.44).

Distance between Consecutive Locations

Because we were interested in the effect of RMAs on the distance moved between successive locations, elk associated with RMAs (>30% association) and alive during both phases of the study (n = 14) were of primary interest. All 14 of these elk decreased average distance moved between successive locations (ADMSL) between the pretreatment and RMA phases of the study (Table 2), and there was a significant ($P \leq 0.05$) decrease in ADMSL between the 2 time periods (mean change = −42.7 m, SD = 25.6, paired-t = −6.07, P = 0.0001). In contrast, there was no significant change in ADMSL for control elk (mean change = 13.6 m, SD = 29.4, paired-t = 1.10, P = 0.32; Table 3). The difference in ADMSL between the time periods (RMA minus pretreatment) was negatively correlated (r = −0.44, P = 0.05) with the degree of elk association with RMAs (Fig. 2). For the 31 elk in the RMA phase of the study, ADMSL was negatively correlated (r = −0.42, P = 0.02) with the degree of elk association with RMAs (Fig. 3). When 2 outlying datapoints were removed,

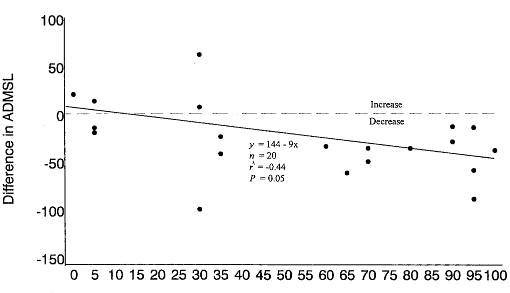

Fig. 2. Relation between the average distance moved between successive locations (ADMSL) between the pretreatment and RMA (Road Management Area) phases and the percent of an elk's home range that was associated with a RMA in the Oregon Coast Range, 1991–94.

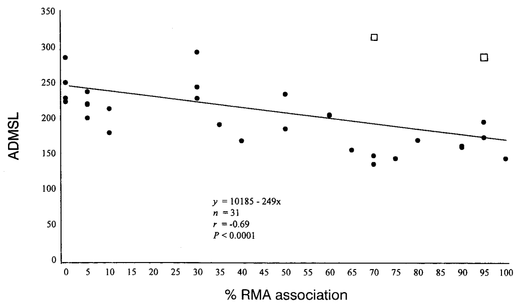

Fig. 3. Relation between the average distance moved between successive locations (ADMSL) and the percent association of an elk's home range with a Road Management Area during the RMA phase (outliers denoted by squares), in the Oregon Coast Range, 1993–94.

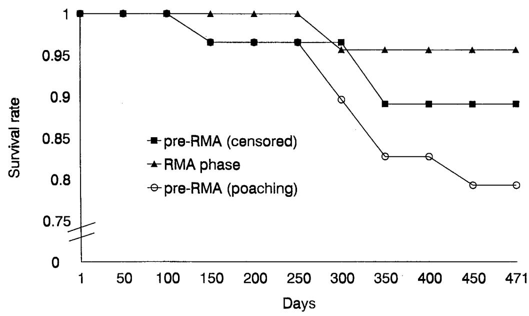

Fig. 4. Survival rates of cow elk in the Oregon Coast Range during the pretreatment and RMA (Road Management Area) phases treating elk disappearances in the pretreatment phase as transmitter failures (censored) or poaching mortality.

this correlation was more significant ($r = -0.69$, $P < 0.0001$). Both of these outliers were elk that had large bimodal home ranges. Most foraging areas for these elk were located on the periphery of their home ranges and were separated by large areas of the closed canopy, pole-sized trees. Elk avoided these habitats, and large ADMSL values for these elk may have been the result of movements between the activity centers at opposite ends of the home ranges (Pope 1994). Therefore, we believe the removal of these outliers was justified, and we present supporting statistics (Fig. 3). In summary, these results indicate that elk moved shorter distances between successive locations in areas influenced by limited vehicle access the most.

Causes of Mortality and Survival Rates

During the pretreatment phase, there were 3 mortalities and 3 disappearances of radiocollared elk. The 3 confirmed mortalities were by poaching (Table 4). There were 3 total mortalities and 1 disappearance during the RMA phase, and all of these animals were associated with RMAs (Table 4). Two elk were harvested legally in antlerless rifle seasons. No cause of death could be determined for the other recovered elk.

After the removal of the gates (post-RMA phase), there were 5 mortalities and 3 disappearances between 1 September 1994 and 31 March 1995 (7 months). Poaching accounted for 1 of the mortalities, and cause of death for the 4 other mortalities was unknown (Table 4). Expected life for these transmitters was 36 months, and all 3 of the elk that disappeared during the post-RMA phase were captured in March 1991. Because these disappearances occurred beyond the expected transmitter life, they were considered transmitter failures, and these observations were censored from the post-RMA interval.

Survival of cow elk for the pre-RMA phase was 0.891 (95% CI = 0 .775–1.00), and the comparable estimate for the RMA phase was 0.957 (95% CI = 0 .873–1.00). These survival curves were not significantly different ($\chi^2 = 1.41$, $P = 0.24$; Fig. 4). However, if elk that

Table 4. Transmitter frequency. fate, and month and year of mortality for radiocollared elk in the southern Oregon Coast Range, March 1991–March 1995.

Carcass found, unknown cause		Disappeared, loss of radio signal		Poaching		Legal hunting	
Freq.	Date	Freq.	Date	Freq.	Date	Freq.	Date
4.351	4/93	4.441	12/91	4.211	7/91	4.461	12/92
5.052	9/94	4.571	1/92	4.611	2/92	5.021	12/93
4.232	12/94	4.041	5/92	4.591	2/92		
4.532	1/95	4.491	12/92	4.611[a]	1/95		
5.081	2/95	4.081[b]	1/95				
		4.370[b]	1/95				
		4.390[b]	3/95				

[a] Re-used collar on new animal.
[b] Disappeared after expected transmitter life.

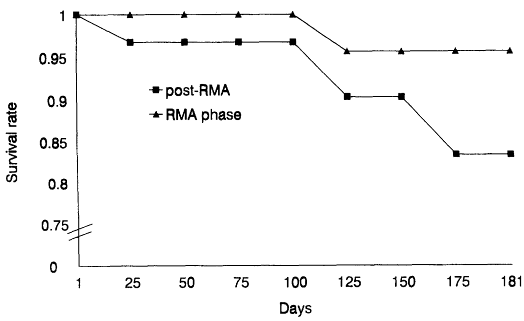

Fig. 5. Survival rates for cow elk in the Oregon Coast Range during the RMA (Road Management Area) and post-RMA phases, 1993–95.

disappeared actually were poached and not censored from the data, the survival estimates were 0.793 (95% CI = 0.646–0.941) for the pre-RMA and 0.957 for the RMA phase. These survival curves were significantly different ($\chi^2 = 4.52$, $P = 0.03$; Fig. 4). Survival of cow elk for a 7-month interval following removal of the RMA gates was 0.834 (95% CI = 0.700–0.967), and survival for a seasonally comparable segment of the RMA phase was 0.957 (95% CI = 0.873–1.00). These survival curves were significantly different ($\chi^2 = 3.76$, $P = 0.05$; Fig. 5).

DISCUSSION

We saw a reduction of core area and home range size in the RMA phase compared to the pretreatment phase for elk associated with RMAs, and no reduction for control elk between the time periods. Although statistical power was too low to detect differences in core area or home range size between the time periods for control elk, mean change was only −18.3 ha for core area and 0.00 ha for home range. The magnitude of the reduction was far greater for RMA related elk (core area = −93.7 ha, home range = −110.6 ha) which indicates that the gates reduced large-scale elk movements. Similarly, Basile and Lonner (1979) examined Rocky Mountain elk in Montana and found that road closures reduced "en masse" elk movements to less accessible areas. Our study provides the first evidence that limited vehicle access produces similar reductions in large-scale movements for Roosevelt elk.

Despite the reduction in core area and home range size, elk did not shift their movements into RMAs. Because we used paired *t*-tests to compare differences in individuals between both time periods, variability among individual elk was not a factor, and differences should be treatment related. Thus, the data failed to support this hypothesis. Other researchers found that Rocky Mountain elk selection of home range was related to forage and cover availability (Irwin and Peek 1983), and found no significant change in home range fidelity between Rocky mountain elk subjected to logging disturbance and those that were not (Edge et al. 1985). Thus, elk appear to respond to disturbance by reducing movements and shifting activity within their home range rather than changing the location of their home range and core activity areas.

Distance Moved between Consecutive Locations

Because elk in this study area are hunted legally and pursued by poachers, they are probably sensitive to human disturbance. This disturbance may be detected more accurately by measuring elk movement within home ranges rather than by changes in the locations and size of home ranges. Therefore, we hypothesized that ADMSL would decrease for elk during the RMA versus the pretreatment phase, and any difference in ADMSL would be correlated with the degree of elk association with RMAs. Although ADMSL does not provide an absolute measure of the actual distance moved in a 24-hour period, it is a relative measure of movements that is comparable between study periods.

We documented a reduction in ADMSL between the pretreatment and RMA periods for RMA associated elk but not control elk. This indicates that the RMAs reduced disturbance and elk movement within their home ranges. Although power was too low to detect a change between the time periods for control elk, the paired *t*-test for control elk had sufficient power to detect the change in ADMSL found in RMA associated elk (change = −42.6 m, power = 0.81). The change in ADMSL for RMA related elk and the lack of change for control elk provides compelling evidence that the gates reduced daily elk movements. The negative correlation between the difference in ADMSL (RMA minus pretreatment) and the degree of elk association with RMAs supports this relation. Also, during the RMA phase only, ADMSL was negatively correlated with the degree of elk association with RMAs. These results suggest a strong relation between RMAs, decreased human disturbance, and reduction in elk movements.

Other researchers have found that human disturbance can increase elk movements. Elk moved greater distances away from logging activity than toward it in western Montana (Edge 1982). When researchers continuously monitored both hunter and elk movements in Oregon's Blue Mountains they found that elk did not move substantial distances until they encountered hunters or vehicles (Bryant et al. 1991). When elk were disturbed during their study, they would move a substantial distance and then remain in that area until they encountered a hunter or a vehicle again. The type and degree of disturbance, cover availability, and season may affect the distance elk move after a disturbance (Marcum 1975).

Mortality Causes and Survival Rates

From April 1991 to 31 March 1995 there were 11 confirmed elk mortalities and 7 disappearances among 41 elk. Four of the confirmed mortalities were due to poaching, 2 were legal hunting, and 5 were unknown but probably were age, disease, or parasite related. No carcasses exhibited evidence of cougar depredations. Four of the disappearances occurred within the expected transmitter life and were probably poaching mortalities, as poaching is the most likely source of mortality that would result in a missing elk. Transmitter failure was unlikely within expected transmitter life, and there were no sightings of marked elk following the disappearance of the radiosignals, even though the elk bands from which animals disappeared were frequently observed (Pope 1994, Cole 1996). High poaching rates are not surprising in a heavily roaded landscape in rural areas. Poaching was the dominant source of mortality on cow Roosevelt elk in the Oregon Cascades (Stussy et al. 1994).

Potential bias in hunter or poacher selection of collared elk was a possibility. The highly visible collars and eartags on the marked elk may have caused either an avoidance or increased likelihood of the elk being shot. Personal communication with hunters in the study area suggested that some hunters would avoid shooting collared elk because they feared it was illegal, and some would not preferentially kill the collared elk, but would shoot them if they presented the best opportunity. In Idaho most hunters did not know that the elk that they shot was collared until the animal was recovered (Unsworth et al. 1993). It was not possible to assess these potential biases in this study.

Survival Related to Road Management Areas

We hypothesized that the presence of RMAs would decrease poaching mortality. Accordingly, there were no poaching mortalities during the RMA period; poaching occurred before installation and after removal of gates. Two legal hunting mortalities occurred behind gates during the RMA period. The gates were not intended to discourage legal hunting opportunities, and as with a similar limited vehicle access program in northeastern Oregon (Coggins and Magera, unpubl. data), legal hunting opportunities probably were enhanced for energetic hunters.

This road management strategy apparently increased cow survival rates. If elk that disappeared within expected transmitter life are considered poaching mortalities, there was a significant increase in survival during the RMA period compared to the pre-RMA period. Gates probably discouraged poachers from shooting at elk from vehicles and would make recovery of animals difficult and risky. In the post-RMA interval, cause of most mortalities was unknown, but there was a decrease in survival rate following the removal of the gates. Road closures may have little effect on legal elk harvest rates (Basile and Lonner 1979), and poaching mortality sites are closer to open roads than legal hunting mortality sites (Smith et al. 1994), but there is no published information available on the influence of road closures on elk mortality due to illegal poaching. Our data are the first evidence of such a relation.

Studies of radiocollared elk have estimated similar survival rates. Roosevelt elk annual survival in the Oregon Cascades was 0.89 (Stussy et al. 1994). Annual survival rates for hunted Rocky Mountain cow elk are also similar; Unsworth et al. (1993) estimated annual survival of 0.886 in Idaho. These values are comparable to those (0.793–0.967) of this study.

MANAGEMENT IMPLICATIONS

Managers should consider the conditions and timing of RMAs in this study before implementing road closures or road management programs. The gates did not provide true road closures, but limited vehicle access to ≤ 4 trips per week for forest management activities, wildlife research, fire suppression and emergency access. By definition, road closures prevent all vehicle access, and in some cases the road surface is destroyed, seeded and no longer maintained. Although this assumption requires testing, true closures probably would have a greater effect on elk behavior than the limited-access of this study. In addition, the elk had only 9 months to acclimate to the limited access program. With more time to respond to RMAs and/or complete closures, the effects of road management on elk behavior may have been stronger.

Elk did not shift home ranges or core areas into RMAs after the gates were installed. To maximize benefits, future road management programs should limit vehicle access on as much of an elk's range as possible. However, limited-vehicle access reduced core area size, home range size, and daily movements of elk. Reduction in elk movement was likely a reaction to decreased vehicular traffic and human harassment of elk, so elk benefitted from limited-access management. Reduced movement suggests that elk expend less energy when associated with RMAs than when they are not. The potential benefits of reduced energy expenditure include increased fat reserves, increased survival rate, and increased productivity. In general, limited-access management may increase survival and reproduction of elk populations.

Although elk populations in western Oregon are increasing, illegal harvest of elk is a major issue. We and other researchers (Stussy et al. 1994) found poaching to be an important cause of mortality for female Roosevelt elk. Survival rates increased during the RMA period compared to the pre-RMA period, and declined after removal of the gates. Reduced poaching may result in an increase in elk numbers, which may be desirable depending on the management objectives for a given area.

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